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Underlying Representations in Children's Speech

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By

Jessica Kay Werts

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Student Name (print or type): Jessica Werts

Faculty Supervisor (print or type): Dr. Sherrill R. Morris

Faculty Approval Signature: Sherrill R. Morris

Department of (print or type): Communicative Disorders

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ABSTRACT

Knowledge of a child's underlying phonemic categories would be extremely helpful when working with children with speech-language impairments. Morris (1999) analyzed the speech productions and perceptions of 15 preschool children and grouped them based on their performance on the production and perception tasks. Three groups emerged. The current study reports on acoustic analysis of 8 children's productions of /s/ and /ʃ/. The concept that was expanded upon was that children listen differently to sounds than adults (Nittrouer, Studdert-Kennedy, McGowan, 1989). If the specific acoustic characteristic that children weight so heavily can be determined, that characteristic can be found in the child's productions and thereby help to classify how they perceive different sounds. After gathering acoustic information three groups emerged similarly to the Morris (1999) study. An acoustic pattern was found that is significant enough to have reason to believe that a procedure can be developed so that clinicians can record a child's speech, analyze it and know what the child's underlying phonemic categories are. If this procedure can be validated clinicians will be able to differentially diagnose children easier, therapy will be more directed and more results will be produced.

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INTRODUCTION

Warner Bros. Studio was on to something when they developed the Looney Tunes. Daffy Duck, Tweety Bird, and Sylvester the Cat all have serious articulation disorders, but isn't it cute! There is something about the production of distorted sounds that makes us smile. Most children produce distortions and other articulation errors as they learn new sounds and discover ways to properly produce them. These inaccuracies are normal and will diminish by with age. However, some children continue to struggle far beyond the normal age range. If left untreated, these articulation errors could continue throughout their adult lives. It is the job of speech-language pathologists to treat these articulation disorders while children are young enough to develop proper habits of speech production.

Sylvester the Cat distorts the /ʃ/ sound as in "she" and /s/ as in 'sun', a distortion error often referred to as a lisp. These two sounds are often grouped together and called voiceless sibilants, because of the manner in which they are produced and their high energy output.. Although most children have difficulty producing voiceless sibilants with the accuracy of adult speakers, a more common problem for children is to produce the two sounds different enough for easy discrimination by the listener. Again, this is a normal problem for young children but becomes a more serious problem beyond the age of 3;6 (Smit, Hand, Frellinger, Bernthal, Bird, 1990).

This study extends previous research that assessed children's production and perception of voiceless sibilants. Specifically, acoustic analysis will be used to further describe children's speech productions. Each child's production data will be compared to their perception oftheir own productions. It is hypothesized that three groups of children will emerge:

1. Children whose /s/ and /ʃ/ productions are significantly different based on acoustic measurements and can be split in to two phonemic categories.

2. Children whose /s/ and /S/ productions are not significantly different based on acoustic measurements and probably represent only one phonemic category.
3. Children whose /s/ and /S/ productions are inconsistent with some productions showing acoustic properties of the other phoneme indicating two overlapping phonemic categories.

If such groupings emerge, information concerning the underlying or cognitive representation of phonemes can be extracted. This will allow speech-language pathologists to make more informed intervention decisions and ultimately improve therapy efficacy. The entire focus of treatment would change depending on whether or not the child had two distinct categories of the /s/ and /S/ sounds. If the child had inconsistent productions indicating two different, but overlapping phonemic categories, therapy would focus on the correct production of each sound. However, if the child appeared to have only one phonemic category, therapy would have to revert to a much more basic level in order to help the child understand that /s/ and /S/ are two different sounds.

LITERATURE REVIEW

One of the pioneers in studying children's systems of speech perception is Susan Nittrouer.. Prior to her work on the subject many people believed that children were born with phonemic categories or sound categories that were adult like and never changed throughout development. Nittrouer, Studdert-Kennedy, and McGowan proposed that not only do children have different phonemic categories than adults, but they perceive speech sounds differently than adults (Nittrouer, Studdert-Kennedy, McGowan, 1989). She also paved the way to proving that in the case of sibilants (s/ʃ) children seem to listen more carefully to the F2 transition from or to the adjacent vowel than the fricative noise which is the characteristic adult perception studies have indicated is integral (Nittrouer, 1989). In 1996 she supported her hypothesis by showing that "children's sensitivity to changes in both fricative-noise spectrum and in F2-onset frequency is poorer than that of adults," (Nittrouer, 1996a).

In 2003, Mayo, Scobbie, Hewlett, and Waters investigated the relationship between the "weighting of acoustic cues in speech perception and the development of metaphonemic awareness." This study supports Nittrouer's hypothesis that phonemic awareness may be one of the developmental experiences that encourages changes in cue weighting strategies (Mayo, Scobbie, Hewlett, Waters, 2003). However, it is noteworthy that although there is a strong relationship between metaphonemic awareness and changes in cue weighting strategies they are not causally related (Mayo et. al., 2003).

This is important because there is a developmental trend for perceptual changes in normal children. Although normally developing children were the subjects in the current investigation, it is hoped that the information gathered will give an indication about the disordered population. If this study helps to discover a system that would uncover a child's underlying phonemic categories, it would aid in the development of therapy goals. If the child is using one phonemic category instead of two it is probable that the child also has poor metaphonemic awareness. That is not to say that if you improve the metaphonemic awareness that you would improve the cue weighting strategies.

Morris (1999) determined that adult perceptions of normally developing children's productions do not always match the child's perception ofherlhis own production. Also, it is possible that children weight acoustic characteristics differently than adults do as suggested by Nittrouer's Developmental Weighting Shift (1989) hypothesis. With the Nittrouer investigations in mind, Morris stated that three possible perception alternatives exist. The first group perceived their own word productions in the same way as adults. The second group perceived them less accurately than adults. The third group perceived their intended targets better than adults.

Acoustic analysis of children's speech

Even a small amount of speech produces a wealth of acoustic information. Therefore, it is important to determine the specific acoustic characteristics that will be examined prior to the beginning of a study. In the case of *lsi* and *lSI*, three main measurements have been reported in the literature as being important for this phonemic distinction. They are formant 2 (F2) transitions, the spectral mean, and kurtosis. Each of these acoustic characteristics will be summarized below.

Nittrouer (1989) determined that children pay more attention to the F2 characteristics of the consonant -vowel transition than they do aspects of the fricative noise which is what adults focus on. Nittrouer took measurements of F2 30 milliseconds before the onset of the vowel and exactly at the point of onset of vocal fold vibration.

The spectral moments program was developed as a way to summarize spectral information through a statistical approach. The spectrum is treated as a distribution curve. Four values are then determined: mean, standard deviation, kurtosis, and skewness. Forrest and Miccio (1996) discovered that, "skewness was the most important cue for distinguishing between /s/ and /ʃ/ and was an acoustically distinct contrast prior to being perceived by listeners," in preschool children's productions (Forrest and Miccio, 1996). The goal of their study was to gather more information about, "the acoustic spectra of voiceless fricatives 1) acquired as a result of treatment, 2) acquired under normal developmental circumstances, and 3) produced correctly by children." They found that the spectral moments program was very useful for learning about the processes that occur phonemically for children who have difficulty learning the difference between /s/ and /ʃ/ (Forrest and Miccio, 1996).

Munson (2004) reported on the spectral and temporal variability of children's /s/ productions. Using the spectral mean as the acoustic measurement, he found children's productions of /s/ have significantly greater spectral variability but no significant durational differences. This information pertains to the current study in that it provides a greater understanding of the acoustic characteristics of children's speech which aids in the interpretation of the results.

Previous studies have reported that children perceive /s/ and /ʃ/ differently than adults (Nittrouer). Other researchers have documented three main acoustic measurements in children's speech. While these studies provide a great deal of valuable and novel ideas, they have never been combined. The developmental weighting shift theory (Nittrouer, 1989) has been supported by many other studies while the results of Morris's study (1999) support the idea that the developmental weighting shift affects children's productions and therefore adult and child perceptions of children's speech. Because we know a connection exists between the acoustic characteristics of /s/ and /ʃ/ minimal pairs and a child's perception we can continue by looking at the information about children's perceptual capabilities by analyzing their acoustic productions. The studies by Munson (2004) and Forrest and Miccio (1996) provide a starting point for the acoustic analysis.

METHODOLOGY

Subjects

Acoustic analysis was conducted on the speech samples of eight subjects who were selected from a previous data set of fifteen children aged 3;0 to 4;0 (Morris, 1999) The subjects for the current analyses were selected by diversity of results and quality of audio recordings. All subjects were native speakers of Standard American English and were in the middle to upper middle strata. Four subjects were female and four were male. Four of the subjects had a history of ear infection and four did not. All subjects selected for this investigation passed a hearing screening at the time of testing. Also, all subjects are considered to be normally developing at the time of testing. The *Goldman-Fristoe Test of Articulation (GFTA)* was administered to be sure that all children were normally developing (Morris, 1999).

Table 1: Subject information: Information concerning subject's age, gender, speech, and hearing skills as well as socio-economic status are provided. Children are ordered according to GFTA percentile.

Subject Number	Age	Sex	GFTA percentile	Hearing screening results	History of ear infections
103	3;4	M	16	Pass	Yes/tubes
113	4;1	M	21	Pass	No
129	3;7	F	32	Pass	Yes/tubes
106	3;3	F	54	Pass	Yes
117	3;6	F	56	Pass	No
114	3;5	M	57	Pass	No
128	4;0	F	58	Pass	Yes
107	3;6	M	71	Pass	No

Initial Study Testing Procedures

All testing was done in a quiet room in the child's home. A game was played with the subject in order to elicit the desired response. The child produced a carrier phrase of "Do _ again." The child would produce the phrase with each of the 15 prompted words.

Word List

1. Seat	2. Pete	3. Sheet	4. Feet	5. Po	6. Show
7. Phone	8. Sew	9. She	10. C	11. Pea	12. Food
13. Sue	14. Pooh	15. Shoe			

The speech was recorded using a microphone, laptop and the MultiSpeech software by Kay Elemetrics. Once all of the speech samples were collected another game was played with the children in order to collect perceptual information. The sound files were randomized and played back to the child. Each child was asked to make judgments about the word they heard and the accuracy of their response was recorded. The sound files were phonetically transcribed and two undergraduate students studying speech-language pathology listened to all of the speech segments and indicated what word they thought the child had said. More detailed information about these procedures can be found in the dissertation written by Dr. Morris (1999).

Current Study Testing Procedures

The sound files of the eight children's /s/ and /ʃ/ words were used in the current study. Additional testing procedures were unnecessary.

Acoustic Analysis

In order to determine if there were patterns in the children's productions of the /s/ and /ʃ/ words, the acoustical properties of those sounds were determined.

The demonstration version of the CSpeech program, TF32 was used to analyze the data. The spectral moments aspect of this program was used because it had been used previously in the Forrest and Miccio (1996) study. The desired result was achieved in that study; therefore it was used as a template to begin acoustic analysis.

Procedures for the analysis were:

1. Open file in the TF32 program
2. Click "View-Open-Spec" in order to view the spectrogram
3. Click "Mmt" to view the spectral moments option
4. Click the "TimeFreq A" button at the top of the screen
5. Change the bandwidth from 300Hz to 800Hz
6. Click the "LPC" button, select "endpoints" and "Track"
7. Enlarge the spectrograph section in order to find the transition point easier
8. Move the left cursor to the beginning of the vowel before the sibilant and the right cursor to a point shortly after the transition
9. Click the down arrow on the right side of the screen

Now that the proper view is attained data collection can begin. Using the right cursor find the place where the voice bar begins. This is a vital step in attaining accurate information, unfortunately there are times that it is difficult to tell exactly where to mark the transition. To achieve consistency the transition was marked by placing the cursor exactly on the end of the bottom red line.

During the first stage of data collection the next step would be to place the left cursor exactly 40 milliseconds (or as close as possible) away from the right cursor using the left and right arrow keys on the keyboard. At that point record the data for mean, standard deviation, skewness and kurtosis. Next move the left cursor to 30ms, 20ms and 10ms and record the set of spectral moments data at each point.. The above time slices were chosen because they were the exact time slices used by Forrest and Miccio (1996). Lastly, record the F2 at the point of the transition. We attempted to mimic the Nittrouer (1989) study for our collection ofF2, however we were only able to accurately collect F2 measurements at the onset of voicing. We were not able to collect measurements of F2 30 ms. Before the onset because the program would not supply F2 measurements at this point.. The reason for this is that sibilants do not have formants or resonances. They have similar characteristics called poles and zeros, but the analysis program very correctly did not identify them as formants.

This procedure was used for collecting data for five of the eight children selected. This provided a great deal of data. Two of the measurements, spectral mean and skewness, appeared to differentiate the voiceless sibilants. /s/ had a higher spectral mean (usually over 10) and a negative skewness score while /f/ had a lower spectral mean (usually under 8) and a positive skewness score. A significant pattern was found for the skewness measurement recorded 10 milliseconds before the transition. The /s/ targeted words seemed to have a negative skewness and the /J/ targeted sounds seemed to have a positive skewness. The other significant pattern was that the /s/ targeted words seemed have a mean at 40ms above 10 whereas the /J/ targeted sounds seemed to have a mean at 40ms less than 10.

Only spectral mean and skewness values were collected for the three remaining children's files. Once the remaining files were analyzed according to the patterns found and all the information was compiled and put into a table the data that did not match the pattern was highlighted. Each child's perception of their own productions (from Morris, 1999) was compared with the acoustic characteristics of each specific word.

RESULTS

The perception and production results from the Dr. Morris (1999) study indicated every child had their own pattern of productions and perceptions. Specifically, three of the eight children selected for the current study made errors in their perceptions of adult speech. These errors may simply be a result of child inattention. Attention is almost always a factor when testing children and it is vital to understand that it is possibly a factor contributing to inaccuracy of children's perception results. Of the three children with inconsistencies in the perception of adult speech, two understood only two thirds of their own productions. The remaining five children in the study exhibited accurate perception of adult speech.

Two of the eight children in the current study accurately produced /s/ and /J/ while the other six produced the sibilants with an accuracy range of 43%-88%. There was also a large range in the accuracy of the children's self perception and adults perceptions of the each child's speech. Figures 1-8 display the results for each individual child. The graphs show the target productions the child's production, the child's perception of his or her target, and 2 adults' perceptions of the child's productions.

The results from the acoustic analysis also varied between children. Appendix A shows the original acoustic analysis results of five ofthe eight the children's /s/ and /J/ productions analysis that included all four spectral moments (mean, standard deviation, skewness, and kurtosis) as well as Formant 2 frequency. After studying the skewness of the sibilant at 10 milliseconds before the vowel transition and the mean/centroid of the sibilant at 40 milliseconds before the vowel transition a significant pattern emerged. Therefore, the data was regrouped (Appendix B) to show the pattern of skewness and mean/centroid values for each ofthe voiceless sibilants.

As hypothesized, there appeared to be three groups of children. Four of the eight children seemed to have two distinct phonemic categories, one category for /s/ and one category for /ʃ/. Only one of those four has an extremely consistent separation between the two categories. The other three of four seem to have to different categories but are still learning to produce them more consistently. Three of the eight children seemed to be in a second group of only having one phonemic category. There was one child that seemed to have one phonemic category and understood /s/ but had difficulty differentiating /ʃ/. The other two children in the second group also seemed to have one phonemic category and understood /ʃ/ but had difficulty differentiating /s/. The last group consisted of the remaining child. That child seemed to have two phonemic categories; however they overlapped so that both /s/ and /ʃ/ were too inconsistent to be considered two distinct categories. These results can be found in table below.

t:ahie 2: Perception and Acoustic Results

File #	Child's Perception of /s/	Child's Perception of ///	Adults' Perception of /s/	Adults' Perception of ///	Acoustic Results	Notes
103	Most Correct	Most Correct	Most Correct	Perceived as /s/	/s/ produced consistently /// produced similarly to /s/	2a
106	Most Correct	Most Correct	Most Correct	All Correct	/s/ produced consistently /// produced less consistently	3
107	Most Correct	Most Correct	All Correct	All Correct	/s/ and /// produced consistently	1
113	All Correct	None Correct	All Correct	None correct	/s/ produced inconsistently /// produced more consistently	2b
114	All Correct	Most Correct	Most Correct	All Correct	/s/ produced consistently /// produced more consistently	I
117	Most Correct	Most Correct	Most Correct	Most Correct	/s/ produced less consistently /// produced more consistently	1
128	All Correct	All Correct	All Correct	Most Correct	/s/ produced consistently /// produced less consistently	1
129	Most Correct	Most Correct	Most Incorrect	Most Correct	/s/ produced inconsistently /// produced more consistently	2b

Notes

I. Child has two distinct phonemic categories

2. Probably only one phonemic category
   a. Understands /s/ but not quite sure how to differentiate ///
   b. Understands /// but not quite sure how to differentiate /s/

3. Probably two overlapping categories

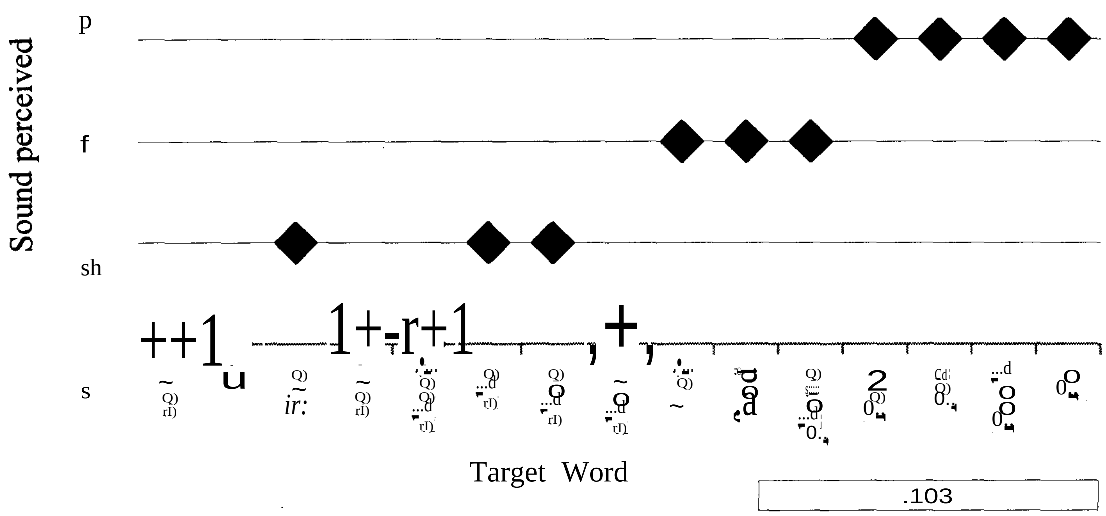
The table below groups the eight children based on the relationship between adult and child perception ofthe child's intended targets. Group A includes four children who perceived their productions similarly to Adult 1 ~79%. Adult 1 and the four children in Group B perceived the children's productions in the same way around 75% of the time.

The two different groupings show that there is still a great deal of work to be done to find consistency. The first table was looking at acoustic analysis and the second table was looking at perceptions and productions. The goal for future studies will be to find a way to come up with the same groups whether the method is acoustic analysis or perceptual analysis.

Table 3: Perception and productions results. Children are grouped according to their ability to perceive their own intended productions. The percentage of self-productions children accurately perceived as target, percentage of adult productions each child accurately understood, , the percentage of child's productions adult 1 perceived as target and are presented.

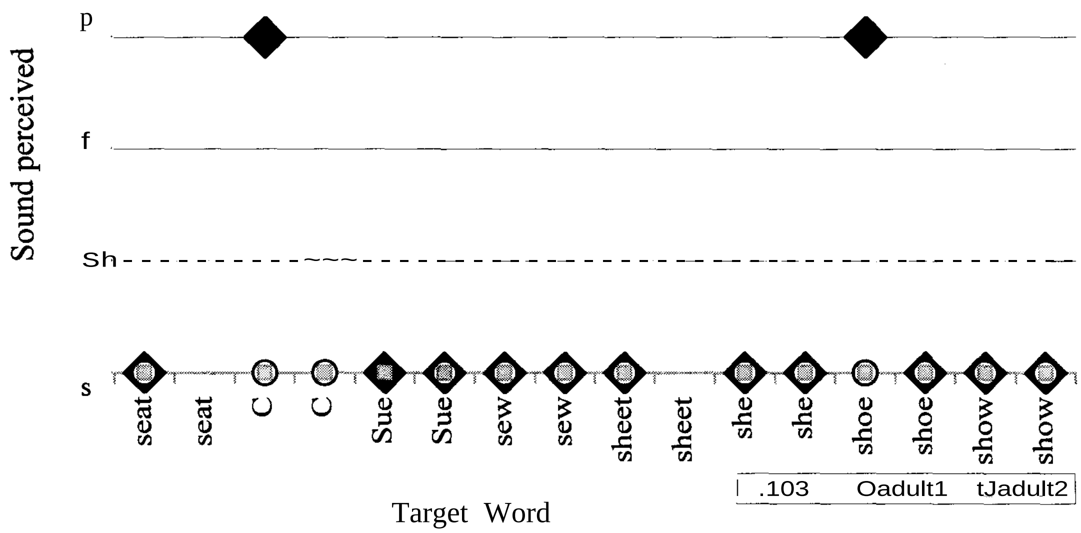
	Percentage of child targets adult 1 and child perceived in the same way	Perceived own intended target	Production of /s/ /f/	Perception of adult speech
Group A				
106	79%	71%	79%	73%
107	87%	87%	100%	100%
113	100%	50%	50%	100%
128	94%	94%	100%	100%
Group B				
103	71%	43%	43%	80%
114	75%	88%	88%	100%
117	75%	69%	88%	100%
129	75%	69%	56%	87%

Figure 1a: Subject I03's perception of adult's speech



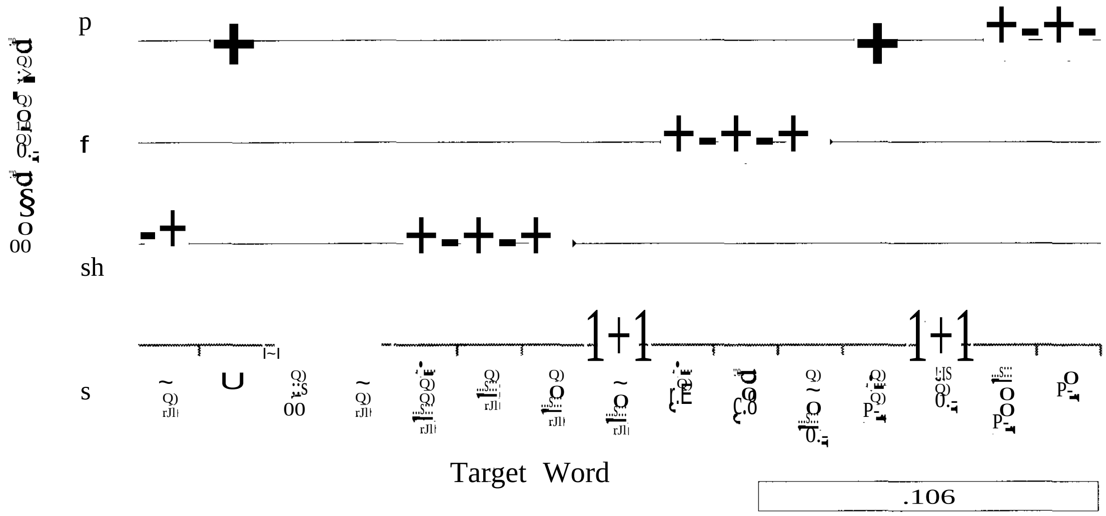
Words not in expressive vocabulary prior to study: Pete, Sue, Po

Figure 1b: Adult and child's perception of I03's productions



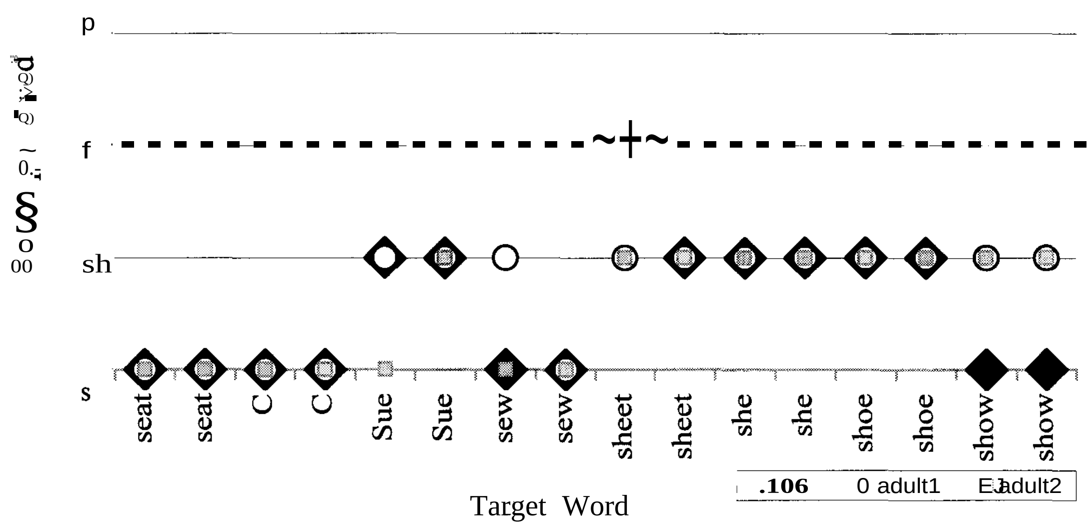
Seat2 and sheet2 were inaccurately saved during data collection
C1 *and* C2 *were semantically confused with 'pea' during testing*

Figure 2a: Subject 106's perception of adult's speech



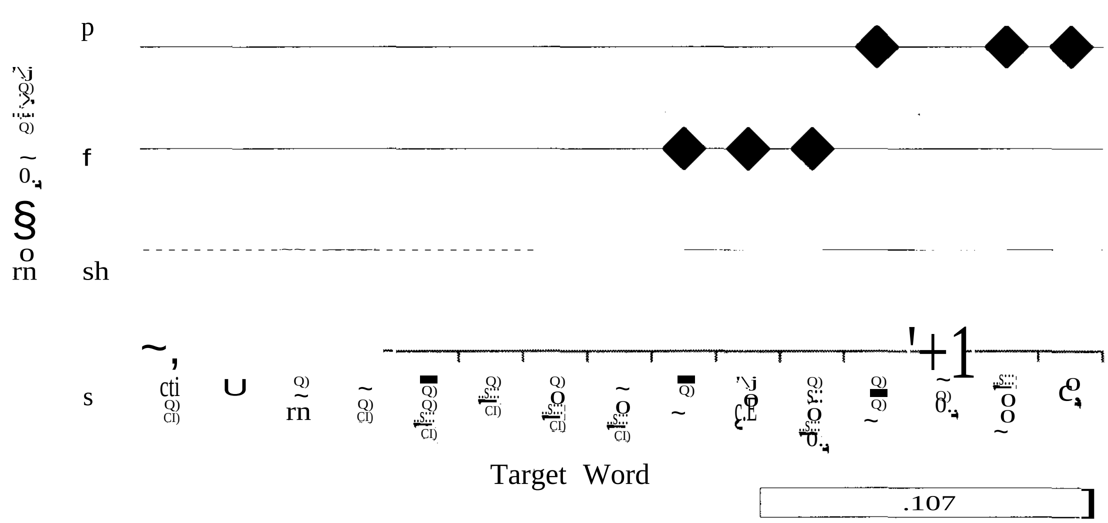
Words not in expressive vocabulary prior to study: Pete, sheet, Sue, sew

Figure 2b: Adult and child's perception of 106's productions



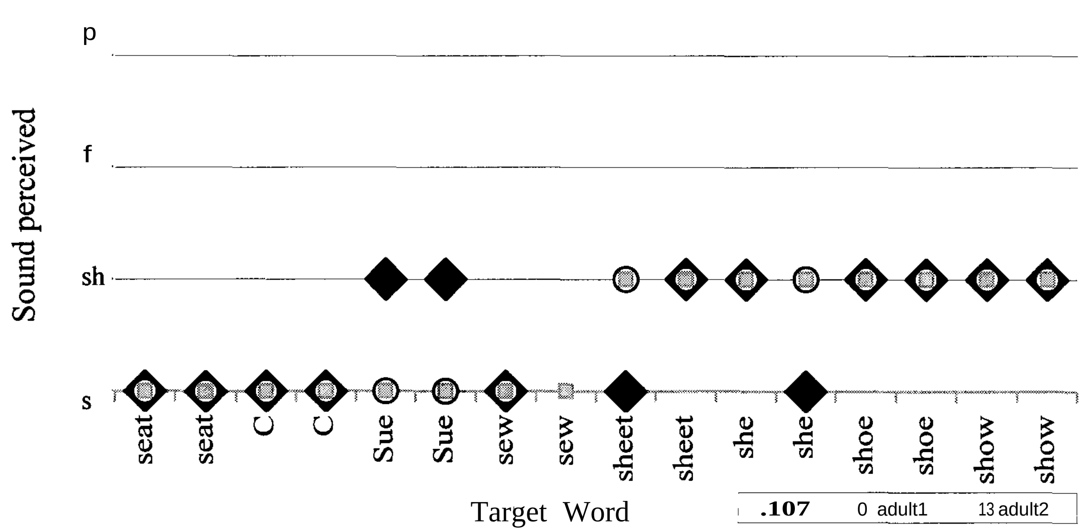
show 1 *and show* 2 *were semantically confused with 'sew' during testing*

Figure 3a: Subject 107's perception of adult's speech



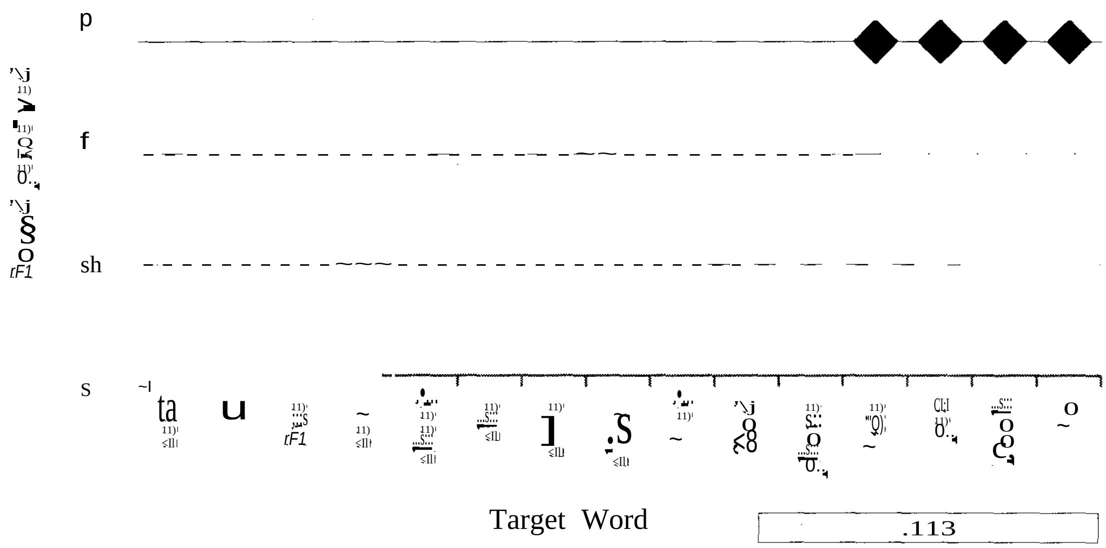
Words not in expressive vocabulary prior to study: Pete and Sue

Figure 3b: Adult and child's perception of 107's productions



sew2 was cutoff

Figure 4a: Subject 113's perception of adult's speech



Words not in expressive vocabulary prior to study: Pete, C, Sue

Figure 4b: Adult and child's perception of 113's productions

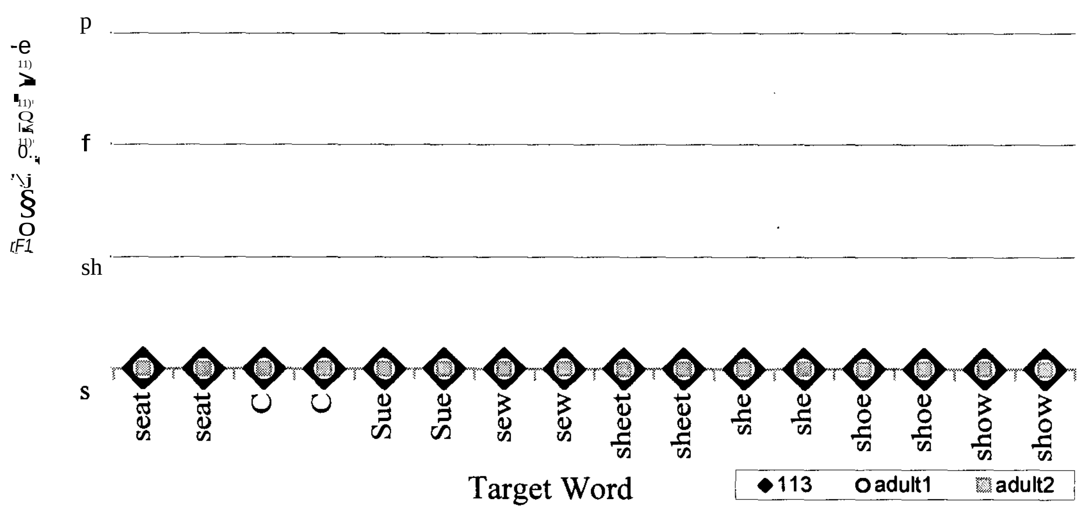
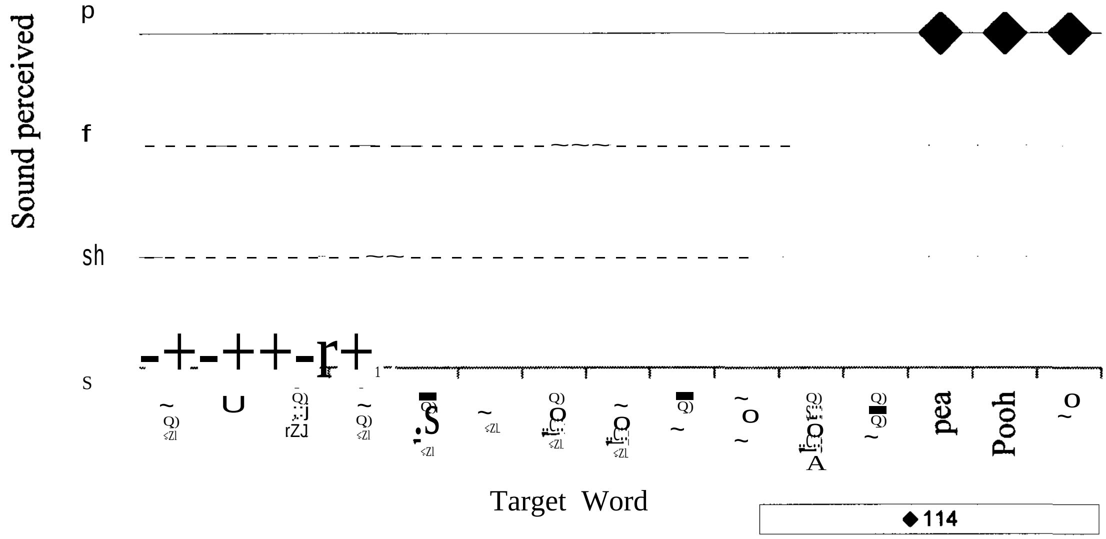


Figure Sa: Subject 114's perception of adult's speech



Words not in expressive vocabulary prior to study: Pete, Po

Figure Sb: Adult and child's perception of 114's productions

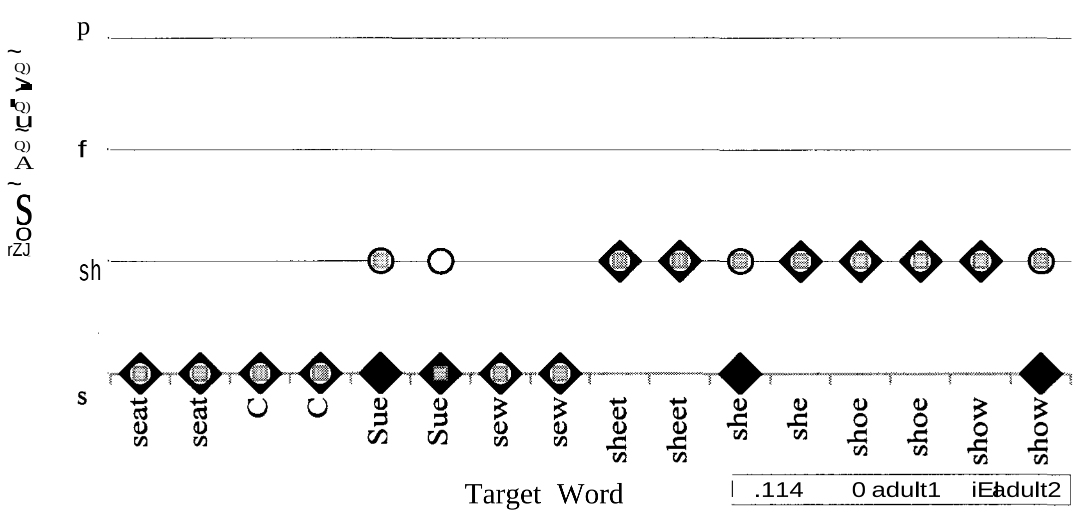
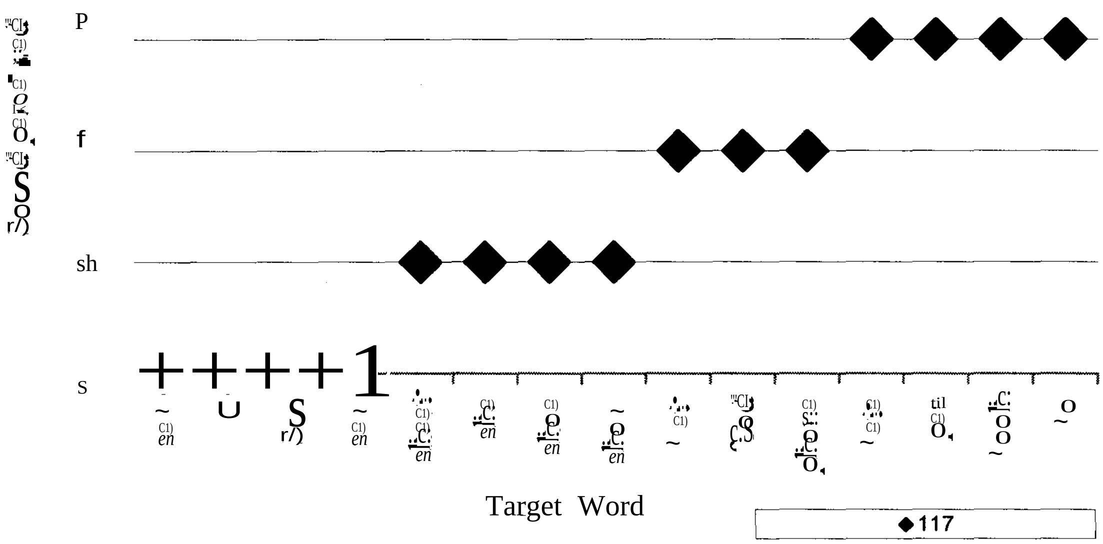


Figure 6a: Subject 117's perception of adult's speech



Words not in expressive vocabulary prior to study: Po

Figure 6b: Adult and child's perception of 117's productions

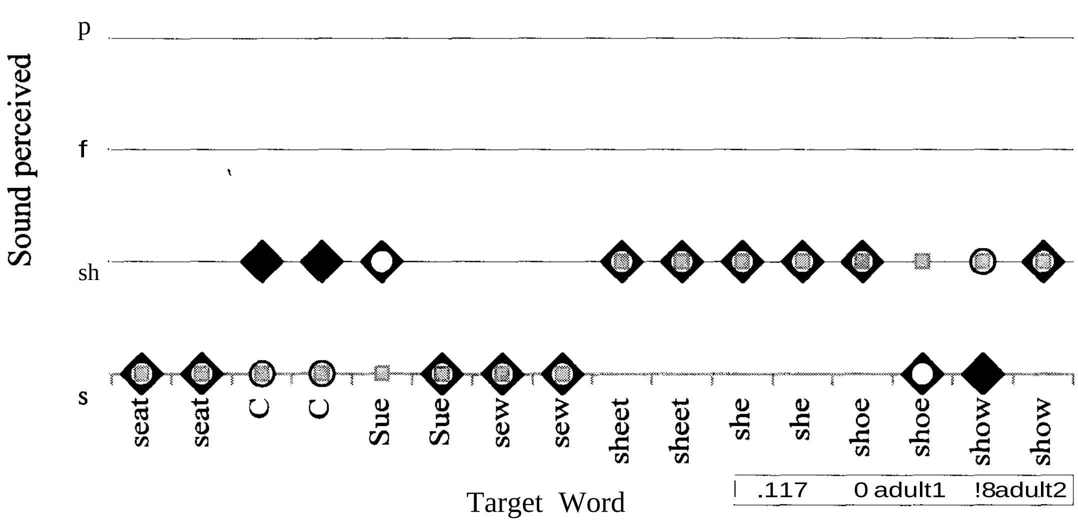
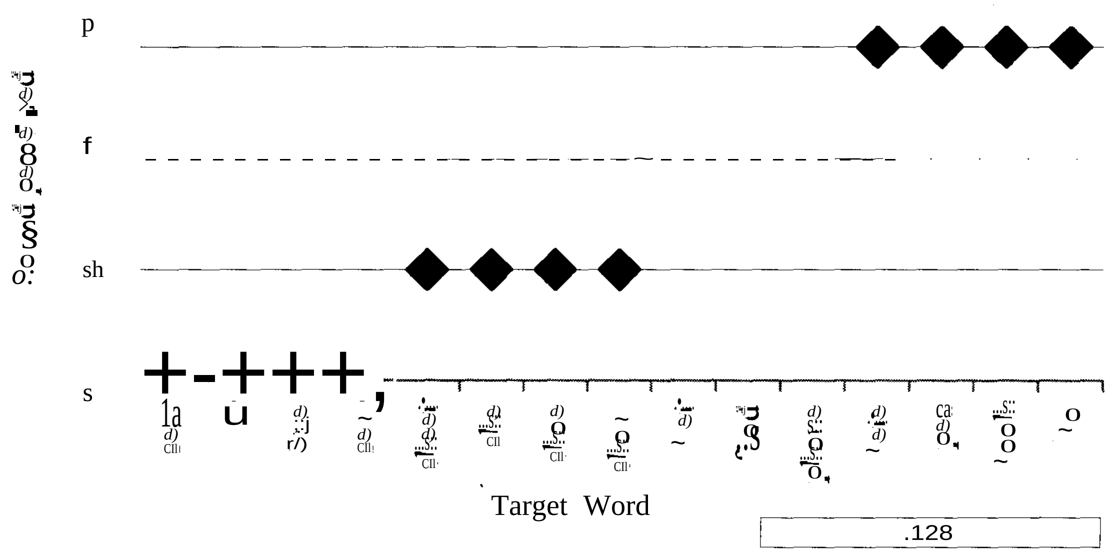


Figure 7a: Subject 128's perception of adult's speech



Words not in expressive vocabulary prior to study: Sue, Po

Figure 7b: Adult and child's perception of 128's productions

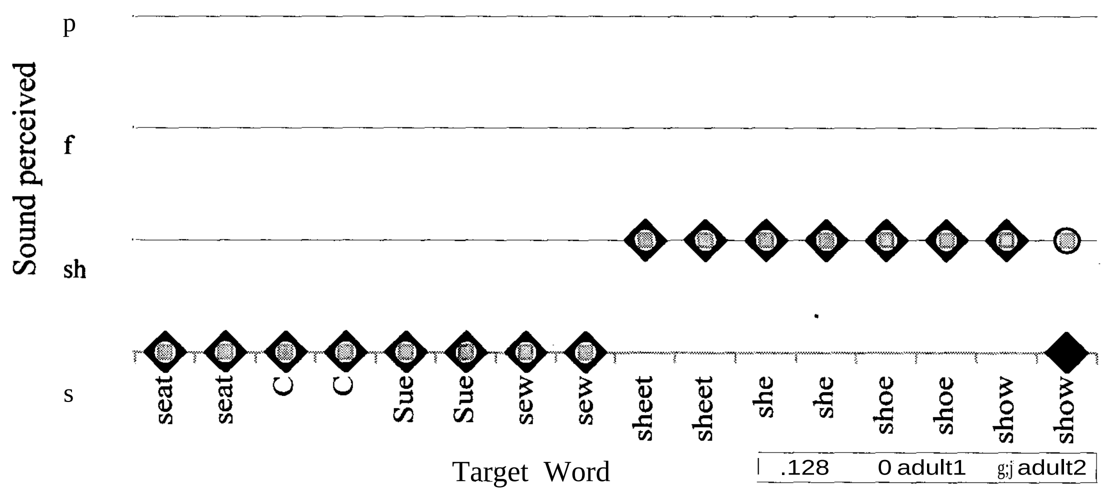
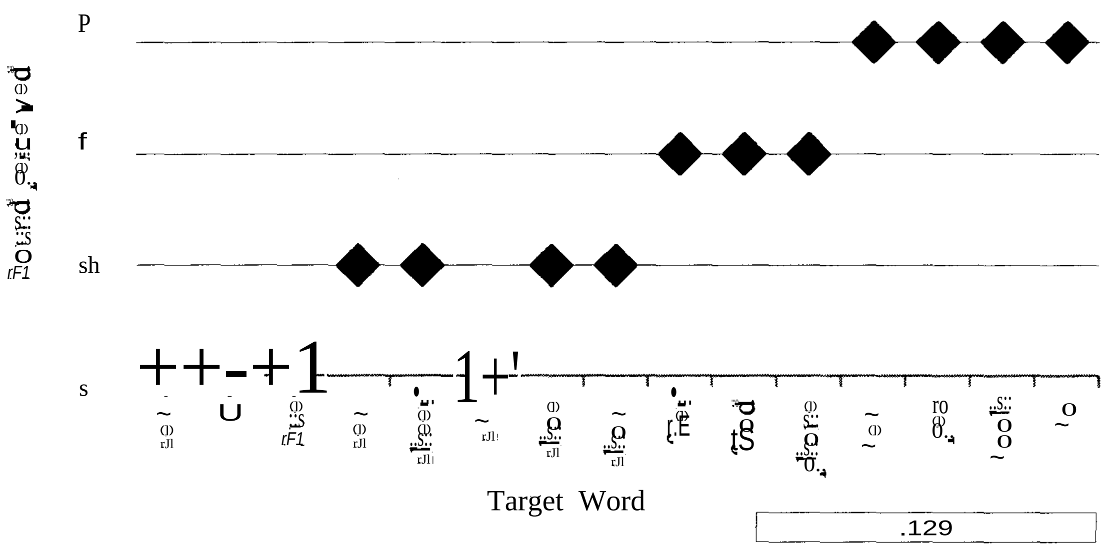
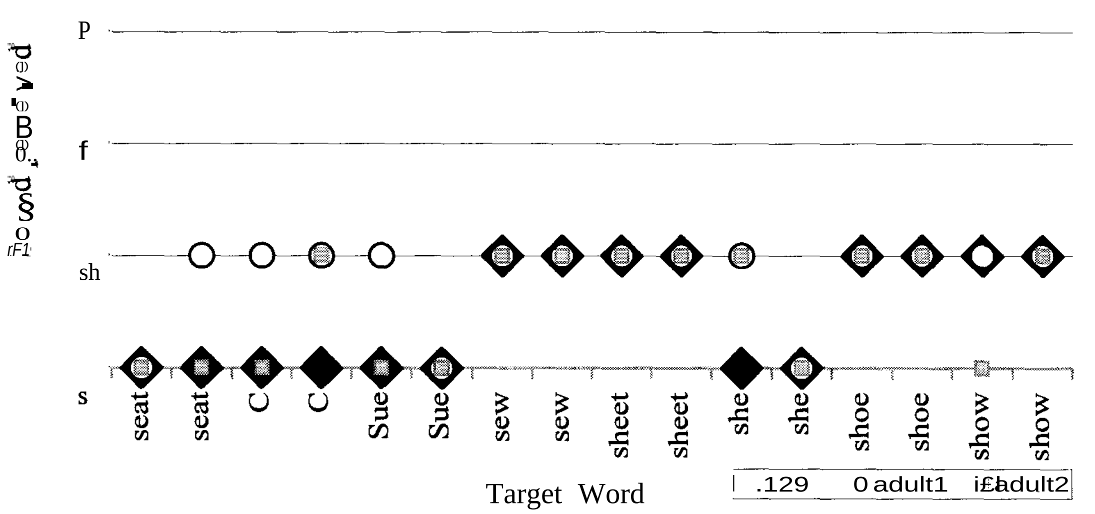


Figure 8a: Subject 129's perception of adult's speech



Words not in expressive vocabulary prior to study: seat, Pete, Sue, sew

Figure 8b: Adult and child's perception of 129's productions



DISCUSSION

Acoustic analysis of children's voices is particularly challenging. Most acoustic analysis software was developed to describe the adult male voice. Because children have shorter vocal tracts and higher frequency voices than adults children's voices exhibit higher frequency resonances and more widely spaced harmonics, respectively. Both of these characteristics provide the acoustic analysis programs with less information from which to determine acoustic values. Further, children's productions are more inconsistent than adult speech making the placement of the cursor for measurements especially critical..

For all these reasons, finding the exact locations and measurements that will give the information desired is extremely difficult.. Moving the cursor very slightly in either direction can corrupt the results so much that they are completely invalid. Because at this time it is extremely difficult to find the exact locations to take measurements, the next step in this investigation should be to continue acoustic and statistic analysis to discover the specific acoustic characteristics that children are focusing on during the perception of their speech. If those characteristic can be found it would help unlock the mystery of children's underlying phonemic representations.

As mentioned previously we know from prior studies that it is possible to uncover children's underlying phonemic representations by way of acoustic analysis. With further investigation, this method of discovering children's underlying phonemic categories could prove very valuable to speech-language pathologists. It is possible that if we understand more about children's perceptions by way of acoustic analysis more accurate differential diagnosis of speech errors can be accomplished. In turn, it would save time and money. The client would benefit greatly and the speech-language pathologist would have a consistent and reliable assessment device.

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APPENDIX A

#103		Spectral Moments					#106		Spectral Moments				
File #	Percieved production						File #	Percieved production					
16	si	mean	stdv	skew	kurt	F2	16	si	mean	stdv	skew	kurt	F2
40ms before		11.833	2.934	-0.431	-0.968		40ms before			Not Available			
30ms before		12.151	2.247	-0.197	-0.223		30ms before						
20ms before		11.698	1.939	-0.024	0.494		20ms before						
10ms before		11.707	2.064	0.352	1.021		10ms before						
F2 0ms						3100	F2 0ms						
18	si	mean	stdv	skew	kurt		18	ʃi	mean	stdv	skew	kurt	
40ms before		11.853	2.859	-0.293	-0.502		40ms before		9.228	2.347	0.771	1.387	
30ms before		11.36	3.208	-0.126	-1.086		30ms before		9.313	2.632	0.852	0.945	
20ms before		12.107	2.838	-0.368	-0.354		20ms before		9.004	2.545	0.756	1.008	
10ms before		11.756	2.328	0.117	0.367		10ms before		8.402	2.972	0.828	0.411	
F2 0ms						3090	F2 0ms						2977
21	ʃo	mean	stdv	skew	kurt		21	ʃo	mean	stdv	skew	kurt	
40ms before		13.386	2.31	-0.74	2.093		40ms before		8.605	2.608	0.775	0.264	
30ms before		13.155	2.179	-0.731	2.561		30ms before		8.566	2.291	0.671	0.639	
20ms before		13.372	2.105	-0.841	2.585		20ms before		9.105	2.543	0.243	-0.468	
10ms before		12.654	1.863	-0.957	5.79		10ms before		9.096	2.449	0.375	-0.341	
F2 0ms						2277	F2 0ms						2487
23	so	mean	stdv	skew	kurt		23	so	mean	stdv	skew	kurt	
40ms before		11.509	1.14	-0.136	12.358		40ms before		11.999	1.564	-0.631	3.164	
30ms before		11.8	1.148	-0.667	7.224		30ms before		11.908	2.218	-0.743	1.368	
20ms before		11.645	1.932	-1.328	4.181		20ms before		11.542	2.544	-0.66	0.588	
10ms before		1.233	2.511	-1.013	1.634		10ms before		11.354	2.84	-0.714	0.452	
F2 0ms						2292	F2 0ms						2855
24	si	mean	stdv	skew	kurt		24	ʃi	mean	stdv	skew	kurt	
40ms before		12.643	2.701	-0.67	-0.232		40ms before			Poor Quality			
30ms before		11.328	2.649	0.049	-0.506		30ms before						
20ms before		10.27	2.942	0.419	-0.838		20ms before						
10ms before		10.559	3.468	-0.191	-0.46		10ms before						
F2 0ms						1103	F2 0ms						
25	si	mean	stdv	skew	kurt		25	si	mean	stdv	skew	kurt	
40ms before		11.127	2.389	0.038	0.459		40ms before			Poor Quality			
30ms before		11.578	2.492	-0.428	0.425		30ms before						
20ms before		11.168	2.731	-0.502	0.106		20ms before						
10ms before		10.305	3.273	-0.575	0.08		10ms before						
F2 0ms						2862?	F2 0ms						

#103						#106					
28 su	mean	stdv	skew	kurt		28 ∫u	mean	stdv	skew	kurt	
40ms before	13.157	2.097	-1.946	6.531		40ms before	10.305	2.794	-0.686	0.271	
30ms before	13.006	2.413	-1.776	4.419		30ms before	10.254	2.621	0.693	1.087	
20ms before	12.147	2.84	-1.303	2.076		20ms before	8.597	3.183	-0.055	-0.935	
10ms before	11.942	3.208	-1.102	0.946		10ms before	7.646	3.376	0.439	-0.658	
F2 0ms					2255	F2 0ms					928
30 su	mean	stdv	skew	kurt		30 ∫o	mean	stdv	skew	kurt	
40ms before	10.962	2.684	-0.229	-0.325		40ms before	7.496	3.128	0.613	-51	
30ms before	11.45	3.127	-0.309	-1.143		30ms before	7.001	3.226	0.886	0.38	
20ms before	10.468	2.641	0.661	0.807		20ms before	7.12	3.309	0.678	0.088	
10ms before	10.471	3.285	0.411	-0.105		10ms before	6.687	3.274	0.927	0.75	
F2 0ms					829	F2 0ms					2846
31 si	mean	stdv	skew	kurt		31 si	mean	stdv	skew	kurt	
40ms before	10.944	2.839	0.084	-0.587		40ms before	10.696	2.39	-0.331	0.018	
30ms before	9.825	2.423	0.313	0.605		30ms before	9.889	2.692	-0.172	-0.63	
20ms before	9.486	2.768	-0.049	0.232		20ms before	9.697	2.867	-0.37	-0.104	
10ms before	9.302	2.988	-0.328	-0.198		10ms before	9	3.368	-0.181	-0.783	
F2 0ms					2982?	F2 0ms					1279
32 si	mean	stdv	skew	kurt		32 ∫i	mean	stdv	skew	kurt	
40ms before	10.783	2.832	0.157	-0.511		40ms before	9.992	1.578	-0.093	2.998	
30ms before	9.809	2.453	0.294	0.492		30ms before	10.043	2.103	-0.807	1.892	
20ms before	9.325	2.842	-0.107	0.157		20ms before	10.22	2.369	-0.812	1.499	
10ms before	9.784	2.844	-0.491	0.381		10ms before	10.079	2.403	-0.963	2.24	
F2 0ms					3033?	F2 0ms					931
33 ∫o	mean	stdv	skew	kurt		33 ∫o	mean	stdv	skew	kurt	
40ms before	12.578	2.638	-0.513	0.317		40ms before	9.422	2.784	0.505	0.275	
30ms before	12.333	2.965	-0.304	-0.619		30ms before	0.953	3.199	0.428	0.35	
20ms before	12.532	3.189	-0.738	0.044		20ms before	10.051	4.114	0.227	-0.558	
10ms before	11.568	3.911	-0.699	-0.335		10ms before	10.916	4.301	0.054	-0.84	
F2 0ms					1636	F2 0ms					2936
34 ∫o	mean	stdv	skew	kurt		34 so	mean	stdv	skew	kurt	
40ms before	10.347	3.592	-0.062	-1.361		40ms before	12.286	2.368	-1.076	2.303	
30ms before	8.797	3.252	0.928	-0.379		30ms before	11.528	2.657	-0.566	1.034	
20ms before	10.635	3.77	-0.014	-1.454		20ms before	10.633	3.761	-0.562	-0.184	
10ms before	8.505	3.237	0.63	0.105		10ms before	10.655	4.319	-0.028	-0.809	
F2 0ms					1263	F2 0ms					2747
35 si	mean	stdv	skew	kurt		35 ∫i	mean	stdv	skew	kurt	
40ms before	10.819	3.096	0.122	-0.747		40ms before	9.71	1.965	-0.914	1.532	
30ms before	10.163	2.713	0.349	-0.144		30ms before	9.434	2.338	-0.646	0.304	
20ms before	9.462	2.357	0.473	0.784		20ms before	9.617	2.741	-0.591	-0.341	
10ms before	9.622	3.087	0.036	-0.474		10ms before	9.932	2.44	-0.854	0.617	
F2 0ms					2028	F2 0ms					1016

#103						
36	51	mean	stdv	skew	kurt	
40ms before		11.594	2.99	-0.081	-0.931	
30ms before		11.651	2.218	-0.415	0.893	
20ms before		11.699	2.167	-0.539	1.311	
10ms before		11.337	2.241	-0.762	2.376	
F2 Oms						2437
37	5U	mean	stdv	skew	kurt	
40ms before		12.79	1.731	-1.048	5.799	
30ms before		12.335	2.204	-1.238	3.623	
20ms before		11.732	2.943	-0.718	0.758	
10ms before		9.777	4.164	-0.188	-0.966	
F2 Oms						1773
38	ſu	mean	stdv	skew	kurt	
40ms before		12.313	1.84	-1.26	3.88	
30ms before		12.082	1.861	-0.965	3.04	
20ms before		11.548	2.571	-1.019	0.974	
10ms before		11.066	2.839	-0.704	0.239	
F20ms						1387

#106						
36	sı	mean	stdv	skew	kurt	
40ms before		10.213	2.654	0.204	-0.66	
30ms before		9.415	2.655	0.131	-0.211	
20ms before		8.855	2.63	0.197	0.659	
10ms before		8.026	2.776	0.407	1.151	
F2 0ms						1172
37	ʃu	mean	stdv	skew	kurt	
40ms before		11.558	2.728	-1.048	0.636	
30ms before		10.317	3.196	-0.247	-0.573	
20ms before		10.12	3.261	-0.174	-0.59	
10ms before		11.195	2.841	-0.685	0.799	
F2 0ms						1163
38	ʃu	mean	stdv	skew	kurt	
40ms before		8.907	2.269	-0.21	0.948	
30ms before		9.316	2.323	-0.469	0.984	
20ms before		8.364	2.988	-0.234	-0.297	
10ms before		8.943	2.561	-0.222	0.951	
F2 0ms						2417

#107							#113						
File #	Percieved production	Spectral Moments					File #	Percieved production	Spectral Moments				
16	si	mean	stdv	skew	kurt	F2	16	si	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40ms before		13.775	2.337	-1.865	4.464		40ms before		[illegible]	[illegible]	[illegible]	[illegible]	
30ms before		13.263	2.659	-1.493	2.753		30ms before		9.523	3.883	0.545	0.021	
20ms before		12.282	3.093	-1.036	1.02		20ms before		10.815	4.08	-0.011	-0.32	
10ms before		10.557	3.959	-0.301	-0.959		10ms before		11.639	3.531	-0.266	0.609	
F2 Oms						1486	F2 0ms						2800
18	Ji	mean	stdv	skew	kurt		18	su	mean	stdv	skew	kurt	
40ms before		6.515	2.423	1.71	3.835		40ms before		8.431	3.151	1.812	2.993	
30ms before		6.112	2.574	1.726	3.294		30ms before		9.207	4.279	1.027	-0.149	
20ms before		6.893	2.615	0.946	1.372		20ms before		11.387	4.51	0.179	-1.11	
10ms before		7.683	3.019	0.654	0.563		10ms before		12.256	4.658	-0.82	-1.185	
F2 Oms						2540	F2 0ms						1745
21	j'o	mean	stdv	skew	kurt		21	so	mean	stdv	skew	kurt	
40ms before		8.049	2.852	0.484	1.026		40ms before		9.317	2.607	1.199	1.379	
30ms before		8.096	2.921	0.44	1.121		30ms before		9.314	2.501	1.088	1.834	
20ms before		8.011	3.91	0.23	-0.375		20ms before		8.898	2.761	1.352	2.976	
10ms before		6.99	4.381	0.527	-0.423		10ms before		8.898	3.333	1.297	1.898	
F2 Oms						2659	F2 0ms						2211
23	so	mean	stdv	skew	kurt		23	so	mean	stdv	skew	kurt	
40ms before		9.559	4.198	0.071	-1.177		40ms before		8.646	2.304	0.953	1.327	
30ms before		8.518	4.53	0.577	-0.954		30ms before		8.464	2.473	0.791	1.279	
20ms before		9.777	5.05	0.207	-1.15		20ms before		8.629	3.186	0.704	0.637	
10ms before		11.587	4.984	-0.36	-0.531		10ms before		9.147	3.575	0.754	0.537	
F2 Oms						2308	F2 0ms						1912
24	Ju	mean	stdv	skew	kurt		24	si	mean	stdv	skew	kurt	
40ms before		7.287	2.341	1.195	2.956		40ms before		11.481	4.636	0.147	-1.337	
30ms before		7.014	1.899	1.545	7.906		30ms before		12.655	4.168	-0.208	-0.705	
20ms before		5.573	3.416	1.053	2.247		20ms before		13.292	4.247	-0.524	-0.523	
10ms before		2.298	3.676	1.666	2.918		10ms before		13.043	4.19	-0.485	-0.382	
F2 Oms						2184	F2 0ms						1912
25	si	mean	stdv	skew	kurt		25	si	mean	stdv	skew	kurt	
40ms before		11.839	2.951	-0.816	1.355		40ms before		9.01	2.642	0.641	1.082	
30ms before		8.753	3.638	0.348	-0.483		30ms before		8.818	2.931	0.977	1.416	
20ms before		7.779	4.106	0.241	-0.222		20ms before		8.519	3.225	1.094	0.795	
10ms before		5.621	5.814	0.632	-1.007		10ms before		9.127	3.454	0.802	-0.18	
F2 Oms						2830	F2 0ms						2268

#107							#113						
28	su	mean	stdv	skew	kurt		28	ʃu	mean	stdv	skew	kurt	
40ms before		11.846	3.4	-0.47	-0.351		40ms before		8.228	3.009	1.246	2.438	
30ms before		11.873	2.954	-0.394	0.071		30ms before		8.838	3.823	0.726	0.358	
20ms before		11.397	3.137	-0.644	0.126		20ms before		9.797	4.857	0.27	-0.631	
10ms before		10.236	3.434	-0.078	0.598		10ms before		10.656	5.387	-0.154	-0.949	
F2 0ms						2865	F2 0ms						2226
30	ʃu	mean	stdv	skew	kurt		30	su	mean	stdv	skew	kurt	
40ms before		6.313	2.767	1.196	3.155		40ms before		8.12	2.591	1.63	3.68	
30ms before		6.62	3.726	1.307	1.619		30ms before		7.693	2.534	1.944	5.65	
20ms before		6.808	4.873	0.902	-0.115		20ms before		7.989	2.684	1.714	5.041	
10ms before		6.296	5.86	0.642	-0.893		10ms before		8.246	3.341	1.297	2.195	
F2 0ms						2483	F2 0ms						2254
31	si	mean	stdv	skew	kurt		31	si	mean	stdv	skew	kurt	
40ms before		12.009	2.404	-1.333	2.014		40ms before		9.552	2.909	0.581	-0.674	
30ms before		11.466	3.235	-0.905	0.34		30ms before		9.515	3.05	0.615	-0.697	
20ms before		10.983	3.662	-0.176	-0.309		20ms before		10.172	3.388	0.207	-1.092	
10ms before		11.064	4.702	-0.541	-0.225		10ms before		10.17	3.218	0.176	-0.757	
F2 0ms						1788	F2 0ms						2653
32	ʃi	mean	stdv	skew	kurt		32	si	mean	stdv	skew	kurt	
40ms before		9.523	2.633	0.116	0.056		40ms before		9.229	2.634	0.822	0.216	
30ms before		8.443	3.281	0.426	-0.715		30ms before		9.497	2.838	0.344	-0.581	
20ms before		7.536	3.467	0.7	-0.75		20ms before		9.741	3.237	0.135	-0.812	
10ms before		7.512	3.385	0.62	-0.875		10ms before		10.034	3.155	-0.056	-0.362	
F2 0ms						2884	F2 0ms						2748
33	ʃo	mean	stdv	skew	kurt		33	so	mean	stdv	skew	kurt	
40ms before		7.197	3.658	0.952	0.324		40ms before		8.916	2.633	0.353	-0.968	
30ms before		6.698	3.068	1.126	2.056		30ms before		8.648	2.629	0.662	-0.674	
20ms before		5.383	3.394	1.115	1.573		20ms before		7.863	2.341	1.28	1.713	
10ms before		4.737	4.657	1.131	0.628		10ms before		7.194	2.272	2.019	5.867	
F2 0ms						2588	F2 0ms						2086
34	ʃo	mean	stdv	skew	kurt		34	so	mean	stdv	skew	kurt	
40ms before			Not Available				40ms before		8.977	2.599	1.164	1.232	
30ms before							30ms before		9.367	2.3	0.645	0.608	
20ms before							20ms before		9.637	2.437	0.515	0.183	
10ms before							10ms before		8.961	2.611	0.818	1.034	
F2 0ms							F2 0ms						2005
35	ʃi	mean	stdv	skew	kurt		35	si	mean	stdv	skew	kurt	
40ms before		9.782	4.296	-0.055	-1.243		40ms before		8.987	2.561	1.384	2.922	
30ms before		9.981	4.384	-0.062	-1.221		30ms before		9.034	3.388	1.22	0.909	
20ms before		10.225	4.489	-0.347	-0.771		20ms before		10.037	4.249	0.622	-0.775	
10ms before		10.215	4.917	-0.54	-0.711		10ms before		11.301	4.685	0.19	-1.186	
F2 0ms						2122	F2 0ms						2760

#107						
36	si	mean	stdv	skew	kurt	
40ms before		14.699	2.385	-2.24	4.626	
30ms before		13.337	2.912	-0.947	0.121	
20ms before		11.513	2.984	-0.324	-0.43	
10ms before		9.939	2.837	-0.254	-0.48	
F2 Oms						
37	su	mean	stdv	skew	kurt	
40ms before		10.845	4.421	-0.456	-1.066	
30ms before		10.137	4.772	-0.221	-1.513	
20ms before		8.628	5.254	0.352	-1.387	
10ms before		9.058	5.64	0.01	-1.44	
F2 Oms						2531
38	Ju	mean	stdv	skew	kurt	
40ms before		5.947	2.652	1.011	2.268	
30ms before		5.682	3.211	1.277	2.691	
20ms before		3.908	3.861	1.282	1.949	
10ms before		1.822	3.086	2.769	8.737	
F2 Oms						2686

#113						
36	si	mean	stdv	skew	kurt	
40ms before		10.786	2.968	-0.128	-0.187	
30ms before		10.113	3.677'	0.594	-0.369	
20ms before		10.744	3.55	0.627	-0.036	
10ms before		11.249	3,486	0.574	0.124	
F2 0ms						1678
37	su	mean	stdv	skew	kurt	
40ms before		10.879	3.06	-0.193	-0.599	
30ms before		10.217	2.82	0.09	0.154	
20ms before		9.568	3.5	0.465	-0.069	
10ms before		9.947	3.823	0.371	-0.242	
F2 0ms						2135
38	su	mean	stdv	skew	kurt	
40ms before		9.328	2.002	0.903	2.394	
30ms before		9.254	2.034	0.696	2.744	
20ms before		8.717	2.235	0.692	2.437	
10ms before		9.192	3.073	0.435	1.668	
F2 0ms						2244

#114		Spectral Moments				
File #	Percieved production					
16	si	mean	stdv	skew	kurt	F2
40ms before		11.088	2.863	-0.518	0.274	
30ms before		10.501	3.13	-0.574	0.407	
20ms before		10.795	2.951	-1.01	2.941	
10ms before		11.034	2.998	-1.022	3.691	
F2 Oms						3393
18	fl	mean	stdv	skew	kurt	
40ms before		7.137	4.49	1.399	0.874	
30ms before		8.227	5.015	0.852	-0.645	
20ms before		9.211	5.474	0.493	-1.296	
10ms before		10.439	5.264	0.185	-1.291	
F2 Oms						2803
21	*fa*	mean	stdv	skew	kurt	
40ms before		7.265	3.066	1.391	1.592	
30ms before		6.884	2.308	1.878	5.937	
20ms before		7.15	2.092	1.664	7.318	
10ms before		6.885	2.672	0.695	2.743	
F2 Oms						1939
23	so	mean	stdv	skew	kurt	
40ms before		12.839	2.019	-1.705	6.573	
30ms before		12.768	2.578	-1.579	3.777	
20ms before		9.481	4.72	-0.236	-1.26	
10ms before		5.747	5.457	0.482	-1.06	
F2 Oms						1897
24	fi	mean	stdv	skew	kurt	
40ms before		7.123	2.555	0.966	2.568	
30ms before		6.994	2.958	0.762	0.976	
20ms before		7.183	3.265	0.841	0.674	
10ms before		7.136	3.384	0.667	-0.154	
F2 Oms						2616
25	si	mean	stdv	skew	kurt	
40ms before		12.025	2.273	-0.977	1.251	
30ms before		12.236	2.228	-1.307	2.626	
20ms before		11.859	2.489	-0.806	0.912	
1--_1_0=m..,...beef_or		M:WilD.1{{	}):~aj&!r	-0.874	2.73	
F2 Oms						2929

#114						
28	ʃu	mean	stdv	skew	kurt	
40ms before		11.274	2.845	-1.235	0.798	
30ms before		10.141	2.821	-0.676	0.191	
20ms before		9.198	2.799	-0.339	0.071	
10ms before		8.587	2.731	0.159	0.204	
F2 0ms						2566
30	ʃu	mean	stdv	skew	kurt	
40ms before		5.075	2.867	1.456	3.866	
30ms before		6.151	3.501	1.305	2.641	
20ms before		6.342	3.329	1.34	3.294	
10ms before		6.04	3.511	1.306	2.498	
F2 0ms						2144
31	si	mean	stdv	skew	kurt	
40ms before		12.472	2.387	-0.791	-0.131	
30ms before		11.174	2.585	-0.455	-0.785	
20ms before		10.422	2.636	-0.572	0.176	
10ms before		9.347	3.615	-0.189	-0.705	
F2 0ms						2961
32	ʃi	mean	stdv	skew	kurt	
40ms before		6.683	2.223	1.949	4.92	
30ms before		6.328	1.991	2.303	8.929	
20ms before		6.305	2.473	2.349	8.309	
10ms before		6.652	2.867	2.046	5.733	
F2 0ms						2828
33	ʃo	mean	stdv	skew	kurt	
40ms before		7.583	2.68	0.893	2.345	
30ms before		7.326	3.021	0.673	1.014	
20ms before		6.65	3.102	0.419	0.858	
10ms before		6.08	4.18	0.865	0.314	
F2 0ms						1984
34	so	mean	stdv	skew	kurt	
40ms before		7.496	1.619	2.254	13.013	
30ms before		8.567	2.087	0.948	2.616	
20ms before		9.55	2.541	0.282	0.306	
10ms before		9.482	3.138	-0.008	-0.245	
F2 0ms						1803
35	ʃi	mean	stdv	skew	kurt	
40ms before		7.102	2.805	1.417	3.456	
30ms before		6.229	2.825	1.119	2.725	
20ms before		5.226	2.892	1.531	3.338	
10ms before		5.712	2.961	1.424	3.147	
F2 0ms						2924

#114						
36	si	mean	stdv	skew	kurt	
40ms before		13.105	1.785	-0.613	1.826	
30ms before		12.946	1.853	-0.739	1.522	
20ms before		12.585	1.976	-0.694	1.784	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	
F2 Oms						[illegible]
37	su	mean	stdv	skew	kurt	
40ms before		10.604	2.263	-0.53	1.13	
30ms before		10.548	2.297	-0.526	0.815	
20ms before		9.771	2.255	0.281	0.787	
10ms before		8.997	1.827	0.856	4.764	
F2 Oms						2263
38	fu	mean	stdv	skew	kurt	
40ms before		10.089	5.013	0.256	-0.979	
30ms before		11.379	5.065	-0.241	-1.025	
20ms before		12.54	4.17	-0.665	0.025	
10ms before		12.837	3.61	-0.915	1.176	
F2 Oms						1897

APPENDIXB

Acoustic analysis data

#	103	mean40ms	skew 10ms	#		mean 40ms	skew 10ms
16	seat	11.833	0.352	18	sheet	11.853	0.117
25	see	11.127	-0.575	24	she	12.643	-0.191
31	seat	10.944	-0.328	32	sheet	10.783	-0.491
36	see	11.594	-0.762	35	she	10.819	0.036
23	sew	11.509	-1.013	21	show	13.386	-0.957
34	sew	10.347	-0.028	33	show	12.578	-0.699
28	Sue	13.157	-1.102	30	shoe	10.962	0.411
37	Sue	12.79	-0.188	38	shoe	12.313	-0.704

#	106	mean 40ms	skew 10ms	#		mean 40ms	skew 10ms
16	seat	no data		18	sheet	9,228	0.828
25	see	11.621	-0.33	24	she	8.797	-0.036
31	seat	10.696	-0.181	32	sheet	9.992	-0.963
36	see	10.213	0.407	35	she	9.71	-0.854
23	sew	11.999	-0.714	21	show	8.605	0.375
34	sew	12.286	-0.028	33	show	9,422	0.054
28	Sue	10.305	0.439	30	shoe	7,496	0.927
37	Sue	11.558	-0.658	38	shoe	8.907	-0.222

#	107	mean 40ms	skew 10ms	#		mean 40ms	skew 10ms
16	seat	13.775	-0.301	18	sheet	6.515	0.654
25	see	11.839	0.632	24	she	vowel error	
31	seat	12.009	-0.541	32	sheet	9.523	0.62
36	see	14.699	-0.254	35	she	9.782	-0.54
23	sew	9.559	-0.36	21	show	8.049	0.527
34	sew	no data		33	show	7.197	1.131
28	Sue	11.846	-0.078	30	shoe	6.313	0.642
37	Sue	10.845	0.01	38	shoe	5.947	2.769

#	113	mean 40ms	skew 10ms	#		mean 40ms	skew 10ms
16	seat	9.196	-0.266	18	sheet	8.431	-0.82
25	see	9.01	0.802	24	she	11.481	-0.485
31	seat	9.552	0.176	32	sheet	9.229	-0.056
36	see	10.786	0.574	35	she	8.987	0.19
23	sew	8.646	0.754	21	show	9.317	1.297
34	sew	8.977	0.818	33	show	8.916	2.019
28	Sue	8.228	-0.154	30	shoe	8.12	1.297
37	Sue	10.879	0.371	38	shoe	9.328	0.435

#	114	mean 40ms	skew 10ms	#		mean 40ms	skew 10ms
16	seat	11.088	-1.022	18	sheet	7.137	0.185
25	see	12.025	-0.874	24	she	7.123	0.667
31	seat	12,472	-0.189	32	sheet	6.683	2.046
36	see	13.105	-1.048	35	she	7.102	1,424
23	sew	12.839	0.482	21	show	7.265	0.695
34	sew	7.496	-0.008	33	show	7.583	0.865
28	Sue	11.274	0.159	30	shoe	5.075	1.306
37	Sue	10.604	0.856	38	shoe	10.089	-0.915

#	117	mean 40ms	skew 10ms	#		mean40ms	skew 10ms
16	seat	13.214	-0.913	18	sheet	9.63	0.078
25	see	9.642	0.778	24	she	9,456	0.318
31	seat	10.214	0.774	32	sheet	9.728	0.26
36	see	12.262	-0.347	35	she	7.313	0,425
23	sew	13.908	-0.892	21	show	9.444	-0.098
34	sew	11.75	0.419	33	show	7.337	0.672
28	Sue	9.07	0.862	30	shoe	9.089	0.618
37	Sue	12.503	-1.508	38	shoe	11.525	-0.588

#	128	mean 40ms	skew 10ms	#		mean 40ms	skew 10ms
16	seat	12.576	-1.452	18	sheet	10.634	-0.473
25	see	12.203	-1.91	24	she	8.927	0.178
31	seat	11.818	-0.315	32	sheet	8.054	0.316
36	see	11.914	0.328	35	she	9.224	-0.677
23	sew	13.098	0.947	21	show	file not available	
34	sew	11.886	-1.355	33	show	7.489	-0.835
28	Sue	13.064	-0.791	30	shoe	8.333	0.416
37	Sue	12.797	-0.286	38	shoe	7.973	-0.014

#	129	mean 40ms	skew 10ms	#		mean 40ms	skew 10ms
16	seat	11.814	0.303	18	sheet	8.807	0.688
25	see	11.051	0.596	24	she	10.08	0.139
31	seat	8.222	-0.263	32	sheet	9.917	0.327
36	see	12.581	-0.707	35	she	9.764	2.084
23	sew	9.627	1.083	21	show	9.012	0.64
34	sew	9.563	0.456	33	show	11.995	0.23
28	Sue	10.453	-0.14	30	shoe	10.872	1.001
37	Sue	9.751	0.296	38	shoe	10.742	0.595

**Shaded cells are the numbers that do no follow the hypothesized pattern